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[Title of Document] SPECIFICATION

[Title of the Invention] WAVELENGTH TUNABLE LIGHT SOURCE

[Scope of Claim for a Patent]

[Claim 1]

A wavelength tunable light source comprising: a semiconductor laser; an ant-reflection film applied onto one end surface of said semiconductor laser; a lens for collimating light made to exit from said one end surface of said semiconductor laser through said anti-reflection film; and a wavelength selection portion constituted by a combination of a diffraction grating and a mirror for selecting light with a desired wavelength and returning the selected light to said semiconductor laser to thereby make laser oscillation,

wherein a center of rotation of said mirror is provided in a position where mode hopping can be suppressed when said wavelength is tuned, and

wherein rotation of said mirror is driven by a direct drive system by using a motor having a rotation shaft in said center of rotation of said mirror.

[Claim 2]

A wavelength tunable light source according to Claim 1, further comprising an optical branching device provided between said semiconductor laser and said diffraction grating for taking

out a part of light with a wavelength selected by said wavelength selection portion, said light taken out by said optical branching device being used as output light.

[Claim 3]

A wavelength tunable light source according to Claim 1 or 2, further comprising:

a rotary arm connected to said rotation shaft of said motor and having a forward end portion to which said mirror is attached; and

rotation quantity detecting means for detecting a quantity of rotation of said rotary arm.

[Claim 4]

A wavelength tunable light source according to Claim 1 or 2, wherein said motor is a servo-motor containing an encoder.

[Claim 5]

A wavelength tunable light source according to Claim 1 or 2, wherein said motor is a voice coil motor having torque only in a rotation range which is set in advance.

[Claim 6]

A wavelength tunable light source according to Claim 3, wherein wavelength information in wavelength scanning is estimated on the basis of an output signal from said rotation quantity detecting means.

[Claim 7]

A wavelength tunable light source according to Claim 4, wherein wavelength information in wavelength scanning is estimated on the basis of an output signal from said encoder.

[Detailed Description of the Invention]

[0001]

[Technical Field pertinent to the Invention]

The present invention relates to a wavelength tunable light source used in the field of light-coherent communication/measuring techniques or the like.

[0002]

[Background Art]

Referring to Fig. 6, a wavelength tunable light source in the background art will be described.

In Fig. 6, reference numeral 1 denotes a semiconductor laser (hereinafter abbreviated to LD), reference numeral 2 denotes a diffraction grating, reference numeral 3 denotes a mirror, reference numerals 5, 6, and 7 denote lenses, reference numeral 8 denotes an optical isolator, reference numeral 11 denotes an optical fiber, and reference numeral 21 denotes a motor.

An anti-reflection film is applied onto one end surface 1a (diffraction grating 2 side end surface) of the LD 1 to avoid

Fabry-Perot resonance between end surfaces of the LD. Light made to exit from the end surface 1a applied the anti-reflection film is converted into collimated light by the lens 6, so that the collimated light is made incident on the diffraction grating 2. Then, among the light incident on the diffraction grating 2, only a light beam having a wavelength selected by a wavelength selection portion constituted by a combination of the diffraction grating 2 and the mirror 3 returns to the LD 1. That is, the end surface 1b of the LD 1 and the mirror 3 form an external resonator to thereby make laser oscillation with the wavelength selected by the wavelength selection portion.

On the other hand, light made to exit from the other end surface 1b of the LD 1 is converted into collimated light by the lens 5. After passing through the optical isolator 8, the collimated light is condensed by the lens 7. The condensed light is taken out as output light through the optical fiber 11. In the wavelength tunable light source, the mirror 3 itself is rotated by the motor 21 so that the wavelength which is to be selected by the wavelength selection portion, that is, the wavelength which is subjected to laser oscillation is made tunable.

In the wavelength tunable light source shown in Fig. 6, however, mode hopping (instantaneous wavelength jumping caused

by hopping of a longitudinal mode of a resonator into an adjacent longitudinal mode) occurred when the wavelength was tunable. Hence, continuous wavelength scanning could not be made. This caused a problem that a long time was required for measuring various kinds of characteristics concerning wavelength such as wavelength loss characteristic.

[0003]

For example, a Rittman-configuration wavelength tunable light source shown in Figs. 7 and 8 is known as a wavelength tunable light source to solve the aforementioned problem. In the wavelength tunable light source, the center of rotation of a mirror 3 is disposed at a specific point (where the resonator length changes in accordance with the selected wavelength so that the longitudinal mode number does not change when the mirror 3 is rotated to tune the selected wavelength) to thereby suppress the occurrence of mode hopping. In the Littmann-mounting wavelength tunable light source, there is generally used a system in which the mirror 3 is attached to a rotary arm 22 having the center of rotation at the aforementioned specific point so that a position (a forward end portion of the rotary arm 22) at a distance of tens of millimeters to 100 mm from the center of rotation of the mirror 3 is pressed by a direct-drive motor 23 to improve wavelength tunable resolving power.

[0004]

[Problem to be solved by the Invention]

In the Littmann-mounting wavelength tunable light source shown in Figs. 7 and 8, however, backlash, stick slip, or the like, occurred in screws or gears used in the inside of the direct-drive motor 23. For this reason, there was a problem that the necessary mirror 3 could not rotate or might be worse in precision of reproducibility even in the case where the rotation shaft of the motor portion rotated.

Moreover, when a stepping motor was used as the direct-drive motor 23, torque fluctuation or velocity fluctuation (see Fig. 3(b)) was theoretically generated in each basic step. Hence, it was difficult to estimate wavelength (position) information in wavelength scanning.

The necessity of measuring characteristics of various kinds of optical parts such as wavelength loss characteristic more speedily and more accurately has risen with the advance of the popularization of dense wavelength division multiplexing (DWDM) in the field of optical communication in recent years. Defective accuracy in wavelength or defective reproducibility caused by such slight torque or velocity fluctuation in wavelength scanning has become a subject of discussion.

[0005]

An object of the present invention is to provide a wavelength tunable light source in which various kinds of characteristics concerning wavelength such as wavelength loss characteristic can be measured speedily and accurately.

[0006]

[Means for Solving the Problem]

In order to solve the above problem, according to an aspect of the present invention stated in Claim 1, for example, as shown in Fig. 1, there is provided a wavelength tunable light source 10 comprising: a semiconductor laser 1; an ant-reflection film applied onto one end surface 1a of the semiconductor laser; a lens 6 for collimating light made to exit from the one end surface of the semiconductor laser through the anti-reflection film; and a wavelength selection portion constituted by a combination of a diffraction grating 2 and a mirror 3 for selecting light with a desired wavelength and returning the selected light to the semiconductor laser to thereby make laser oscillation, wherein a center of rotation of the mirror is provided in a position P0 where mode hopping can be suppressed when the wavelength is tuned, and wherein rotation of the mirror is driven by a direct drive system by using a motor 4 having a rotation shaft 4a in the center of rotation of the mirror.

[0007]

According to the aspect of the present invention stated in Claim 1, the center of rotation of the mirror is provided in a position where mode hopping can be suppressed when the wavelength is tuned, and the rotation of the mirror is driven by a direct-drive system by using the motor having the rotation shaft in the center of rotation of the mirror. Hence, backlash, stick slip, or the like, can be prevented from occurring when the wavelength is tuned, so that the wavelength accuracy and reproducibility can be improved. Moreover, mode hopping can be prevented from occurring over a wide band, so that continuous wavelength scanning can be made with little fluctuation in optical output.

Hence, various kinds of characteristics concerning wavelength such as wavelength loss characteristic can be measured speedily and accurately.

Although the center of rotation used in the Littmann-mounting is typical of the position where mode hopping can be suppressed when the wavelength is tuned, the center of rotation used in another mounting (for example, the center of rotation deduced from measured data or the like) may be used as the aforementioned position. That is, any position may be used if it is the position where the resonator length changes in accordance with the selected wavelength so that the

longitudinal mode number does not change when the mirror is rotated to tune the selected wavelength.

[0008]

According to another aspect of the present invention state in Claim 2, in the wavelength tunable light source defined in Claim 1, for example, as shown in Fig. 5, an optical branching device (for example, a beam splitter 13 or the like) is provided between the semiconductor laser 1 and the diffraction grating 2 for taking out a part of light with a wavelength selected by the wavelength selection portion, and the light taken out by the optical branching device is used as output light.

[0009]

According to another aspect of the present invention stated in Claim 2, a part of light with the wavelength selected by the wavelength selection portion is taken out as output light by the optical branching device. Hence, the naturally emitted light component emitted from the semiconductor laser and contained in the output light can be reduced. That is, pure-wavelength light containing little naturally emitted light can be taken out as output light.

[0010]

According to a further aspect of the present invention stated in Claim 3, for example, as shown in Fig. 4, the wavelength

tunable light source defined in Claim 1 or 2, is constituted by a rotary arm 9 connected to the rotation shaft 4a of the motor 4 and having a forward end portion to which the mirror 3 is attached; and rotation quantity detecting means (for example, an optical encoder 16 or the like) for detecting a quantity of rotation of the rotary arm.

[0011]

According to the further aspect of the present invention stated in Claim 3, the quantity of rotation of the rotary arm can be controlled on the basis of the detection result of the rotation quantity detecting means.

Hence, the position of the rotary arm can be controlled accurately, so that wavelength accuracy and reproducibility can be improved when the wavelength is tuned.

Incidentally, the preferable portion where the quantity of rotation of the rotary arm is detected is the forward end portion of the rotary arm. Hence, the resolving power of the rotation quantity detecting means can be improved.

[0012]

According to a still further aspect of the present invention state in Claim 4, in the wavelength tunable light source defined in Claim 1 or 2, for example, as shown in Fig. 2, the motor 4 is a servo-motor containing an encoder 4b.

[0013]

According to the still further aspect of the present invention stated in Claim 4, the motor is constituted by a servo-motor containing an encoder. Hence, torque or velocity fluctuation can be prevented from occurring in wavelength scanning, so that wavelength accuracy and reproducibility can be improved.

Incidentally, the encoder is preferably a laser encoder of high resolving power. Hence, position detecting accuracy can be improved by the encoder. Even in the case where the rotation of the mirror is driven by a direct drive system, desired wavelength tunable resolving power can be obtained easily.

[0014]

According to another aspect of the present invention state in Claim 5, in the wavelength tunable light source defined in Claim 1 or 2, the motor 4 is a voice coil motor having torque only in a rotation range which is set in advance.

[0015]

According to another aspect of the present invention stated in Claim 5, the motor is constituted by a voice coil motor having torque only in a predetermined rotation range, that is, only in a rotation range required for tuning the wavelength. Hence, the motor becomes inexpensive, high in torque and thin in size.

Moreover, the position of the rotary arm can be controlled accurately so that desired wavelength-tunable resolving power can be obtained easily even in the case where the rotation of the mirror is driven by a direct drive system.

[0016]

According to a further aspect of the present invention state in Claim 6, in the wavelength tunable light source defined in Claim 3, wavelength information in wavelength scanning is estimated on the basis of an output signal from the rotation quantity detecting means.

[0017]

According the further aspect of the present invention stated in Claim 6, wavelength information in wavelength scanning is designed to be estimated on the basis of an output signal from the rotation quantity detecting means. Hence, the time required for estimating wavelength information in wavelength scanning is shortened. Hence, various kinds of characteristics of optical parts concerning wavelength can be measured in a short time.

[0018]

According to a still further aspect of the present invention state in Claim 7, in the wavelength tunable light source defined in Claim 4, wavelength information in wavelength scanning

is estimated on the basis of an output signal from the encoder 4b.

[0019]

According to the still further aspect of the present invention state in Claim 7, wavelength information in wavelength scanning is designed to be estimated on the basis of an output signal from the encoder. Hence, the time required for estimating wavelength information in wavelength scanning is shortened. Hence, various kinds of characteristics of optical parts concerning wavelength can be measured in a short time.

[0020]

[Mode for Carrying out the Invention]

Embodiments of the present invention will be described below with reference to Figs. 1 to 5.

[0021]

[First Embodiment]

Fig. 1 is a diagram showing the schematic configuration of a wavelength tunable light source according to a first embodiment of the present invention.

In this embodiment, the wavelength tunable light source 10 is constituted by an LD 1, a diffraction grating 2, a mirror 3, a motor 4, lenses 5, 6 and 7, an optical isolator 8, and a rotary arm 9. An anti-reflection film is applied onto an end

surface 1a (diffraction grating 2 side end surface) of the LD 1.

[0022]

In the wavelength tunable light source 10 shown in Fig. 1, light rays made to exit from the end surface 1a of the LD 1 are converted into collimated light rays by the lens 6. The collimated light rays are made incident on the diffraction grating 2. Among the light rays incident on the diffraction grating 2, only a part of light rays with a wavelength selected by a wavelength selection portion constituted by a combination of the diffraction grating 2 and the mirror 3 returns to the LD 1. That is, the other end surface 1b of the LD 1 and the mirror 3 constitute an external resonator, so that laser oscillation is made with the wavelength selected by the wavelength selection portion.

On the other hand, light rays made to exit from the other end surface 1b of the LD 1 are converted into collimated light rays by the lens 5. After passing through the optical isolator 8, the collimated light rays are condensed by the lens 7. The condensed light rays are taken out as output light through an optical fiber 11.

[0023]

A rotation mechanism constituted by a combination of the

rotary arm 9 and the motor 4 is further provided in the wavelength tunable light source 10 shown in Fig. 1. The mirror 3 is rotated by the rotation mechanism so that wavelength scanning can be made.

Here, the center of rotation of the mirror 3 coincides with a point P0 of intersection between line segments L1 and L2. The line segment L1 extends perpendicularly to the optical axis with the optical position P1 of the end surface 1b of the LD 1 relative to the diffraction grating 2 (the position of the end surface 1b relative to the diffraction grating 2 when the respective lengths of the lens 6 and the LD 1 are expressed in air) as a start point. The line segment L2 extends from the diffraction surface of the diffraction grating 2. Further, the mirror 3 is turned so that a line segment L3 of extension of the reflection surface of the mirror 3 is directed into a direction which passes through the point P0.

Such mounting of the mirror 3, diffraction grating 2 and LD 1 is called Littmann-mounting. According to this mounting, mode hopping can be prevented from occurring over a wide band, so that continuous wavelength scanning can be made with little fluctuation of the light output. That is, the center of rotation of the mirror 3 is provided in a position where mode hopping can be suppressed when the wavelength is tuned.

As shown in Fig. 2, the motor 4 is constituted by a servo-motor having a laser encoder of high resolving power. Further, as shown in Fig. 1, a rotation shaft 4a of the motor 4 is disposed at the point P0, and a base end portion of the rotary arm 9 is connected to the rotation shaft 4a. The mirror 3 is attached to a forward end portion of the rotary arm 9 so that the mirror 3 and the rotary arm 9 rotate together with the rotation shaft 4a as the rotation shaft 4a rotates. That is, the motor 4 drives the mirror 3 to rotate in a direct drive system.

[0024]

Further, a control portion not shown is electrically connected to the motor 4. The control portion performs feedback control of the motor 4 on the basis of an output signal from the encoder 4b and estimates wavelength information (current wavelength) in wavelength scanning on the basis of the output signal from the encoder 4b. Hence, as shown in Fig. 3, torque or velocity fluctuation or the like occurring in the case of a stepping motor in wavelength scanning can be prevented, so that the time required for estimating wavelength information in wavelength scanning becomes short.

[0025]

That is, according to the wavelength tunable light source described in this embodiment, the center of rotation of the mirror

3 is provided in a position where mode hopping can be suppressed when the wavelength is tuned, and the rotation of the mirror 3 is driven by a direct drive system by using the motor 4 having the rotation shaft 4a provided in the center of rotation of the mirror 3. Hence, backlash, stick slip, or the like, can be prevented from occurring when the wavelength is tuned. Hence, wavelength accuracy and reproducibility can be improved. Moreover, mode hopping can be prevented from occurring over a wide band. Hence, continuous wavelength scanning can be made with little fluctuation of the light output.

Hence, various kinds of characteristics concerning wavelength, such as wavelength loss characteristic, can be measured speedily and accurately.

[0026]

Moreover, the motor 4 is constituted by a servo-motor having an encoder 4b. Accordingly, fluctuation in torque or velocity hardly occurs in wavelength scanning. Hence, wavelength accuracy and reproducibility can be improved. Moreover, the encoder 4b is constituted by a laser encoder. Accordingly, desired wavelength-tunable resolving power can be obtained easily.

Moreover, wavelength information in wavelength scanning is estimated on the basis of the output signal from the encoder

4b. Accordingly, the time required for estimating wavelength information in wavelength scanning becomes short. Hence, various kinds of characteristics of optical parts concerning wavelength can be measured in a short time.

[0027]

The present invention is not limited to the wavelength tunable light source 10 described in this embodiment and various changes or modifications may be made. For example, although this embodiment has shown the case where the motor 4 is constituted by a servo-motor, the present invention may be applied also to the case where the motor 4 is constituted by a voice coil motor having torque only in a predetermined range (such as a swing type voice coil motor which has a voice coil at one end of an arm held rotatably so that the arm is swung when the voice coil is supplied with a current). Also in this case, like the case of a servo-motor, the position of the rotary arm 9 can be controlled accurately so that desired wavelength-tunable resolving power can be obtained easily.

[0028]

Although the first embodiment has shown the case where the motor 4 has the encoder 4b, the present invention can be applied also to the case where the motor has no encoder. In this case, rotation quantity detecting means (external encoder)

maybe preferably provided for detecting the quantity of rotation of the mirror 3 or the rotary arm 9. A transmission type or reflection type optical encoder can be used as the rotation quantity detecting means. When, for example, a reflection type optical encoder 16 is used, an optical scale 16b is disposed at the forward end portion of the rotary arm 9 and a body portion 16a is disposed in a position opposite to the optical scale 16b as shown in Fig. 4. The body portion 16a contains a light-emitting device for irradiating light toward the optical scale 16b, and light-detection devices for detecting A-phase and B-phase rotation signals output from the optical scale 16b. The quantity of moving displacement of the body portion 16a relative to the optical scale 16b and the moving direction thereof are detected on the basis of the A-phase and B-phase rotation signals detected by the light-detection devices respectively. By providing the rotation quantity detecting means thus, the position of the rotary arm 9 can be controlled accurately. Hence, wavelength accuracy and reproducibility can be improved when the wavelength is tuned. By arranging the optical scale 16b in the forward end portion of the rotary arm 9, the resolving power of the rotation quantity detecting means can be improved.

[0029]

[Second Embodiment]

Fig. 5 is a diagram showing the schematic configuration of a wavelength tunable light source according to a second embodiment of the present invention. Except for portions peculiar to the second embodiment, the second embodiment is the same as the first embodiment. In the second embodiment, parts the same as those in the first embodiment are referenced correspondingly and the description of those parts will be omitted.

[0030]

In the second embodiment, as shown in Fig. 5, the wavelength tunable light source 10A has a beam splitter 13 between the diffraction grating 2 and the LD 1. The beam splitter 13 is a kind of optical branching device. That is, light rays with a wavelength selected by the wavelength selection portion are branched into two parts by the beam splitter 13. One part of the light rays returns to the LD 1 whereas the other part of the light rays is condensed by a lens 15 via an optical isolator 14 and taken out as output light through an optical fiber 12.

Hence, according to the wavelength tunable light source 10A described in the second embodiment, light with a pure wavelength little in naturally emitted light component from the LD 1 can be taken out as output light.

[0031]

Although the second embodiment has shown the case where the beam splitter 13 is used as an optical branching device, the present invention is not limited thereto. Any optical branching device may be used in the present invention if diffracted light rays returned from the diffraction grating 2 to the LD 1 can be branched into parts so that one branched part of the light rays can be taken out as output light.

It is a matter of course that various changes or modifications may be made suitably as to the specific detailed structure or the like without departing from the spirit of the present invention.

[0032]

[Effect of the Invention]

According to the aspect of the present invention stated in Claim 1, backlash, stick slip, or the like, can be prevented from occurring when the wavelength is tuned, so that the wavelength accuracy and reproducibility can be improved. Moreover, mode hopping can be prevented from occurring over a wide band, so that continuous wavelength scanning can be made with little fluctuation in optical output.

Hence, various kinds of characteristics concerning wavelength such as wavelength loss characteristic can be measured speedily and accurately.

According to another aspect of the present invention stated in Claim 2, pure single spectrum light little in naturally emitted light component from the semiconductor laser can be taken out as output light.

According to the further aspect of the present invention stated in Claim 3, the position of the rotary arm can be controlled accurately, so that wavelength accuracy and reproducibility can be improved when the wavelength is tuned.

According to the still further aspect of the present invention stated in Claim 4, torque or velocity fluctuation can be prevented from occurring in wavelength scanning, so that wavelength accuracy and reproducibility can be improved.

According to another aspect of the present invention stated in Claim 5, the motor becomes inexpensive, high in torque and thin in size.

According to the aspects of the present invention stated in Claims 6 and 7, the time required for estimating wavelength information in wavelength scanning is shortened. Hence, various kinds of characteristics of optical parts concerning wavelength can be measured in a short time.

[Brief Description of the Drawings]

[Fig. 1]

Fig. 1 is a diagram showing the schematic configuration

of a wavelength tunable light source according to a first embodiment of the present invention.

[Fig. 2]

Fig. 2 is a perspective view showing the motor incorporated in the wavelength tunable light source depicted in Fig. 1.

[Fig. 3]

Figs. 3(a) and 3(b) are graphs for comparing the rotation velocity characteristic of a servo-motor with that of a stepping motor.

[Fig. 4]

Fig. 4 is a perspective view showing an example of configuration of rotation quantity detecting means.

[Fig. 5]

Fig. 5 is a diagram showing the schematic configuration of a wavelength tunable light source according to a second embodiment of the present invention.

[Fig. 6]

Fig. 6 is a diagram showing an example of configuration of a background-art wavelength tunable light source.

[Fig. 7]

Fig. 7 is a diagram showing an example of configuration of a Littmann-mounting wavelength tunable light source.

[Fig. 8]

Fig. 8 is a diagram showing a modified example of the wavelength tunable light source depicted in Fig. 7.

[Description of the Reference Numerals]

1 semiconductor laser

2 diffraction grating

3 mirror

4 motor

4a rotation shaft

4b encoder

5, 6, 7, 15 lens

8, 14 optical isolator

9 rotary arm

10, 10A wavelength tunable light source

11, 12 optical fiber

13 beam splitter (optical branching device)

16 optical encoder (rotation quantity detecting means)